DAILY REAL-TIME, GLOBAL SEA SURFACE TEMPERATURE - High-Resolution Analysis: RTG_SST_HR

By

William Gemmill, Bert Katz[2] and Xu Li[3]

Environmental Modeling Center

National Centers for Environmental Prediction

National Weather Service, NOAA

Camp Springs, MD, 20746

October 2007

NCEP / EMC

OFFICE NOTE

Marine Modeling and Analysis Branch,

Contribution Number 260

[2]Science Application International Corporation

[3]Joint Center for Satellite Data Assimilation, Camp Springs, MD 20746

ABSTRACT

This note describes changes to the daily real-time, global sea surface temperature analysis (RTG_SST) on a ½ degree latitude, longitude analysis, which was originally implemented on 30 January 2001. The new analysis, designated as RTG_SST_HR, was implemented into operations on 27 September 2005 with an increased horizontal resolution at 1/12 degree. The original RTG_SST analysis continues to run in operations to allow for comparisons by users. Each daily product uses the most recent 24-hours of *in situ* and satellite-derived AVHRR ocean surface temperature data and provides a global SST analysis. The new SST's are further based on the new physical retrievals system developed with the Joint Center for Satellite Data Assimilation (JCSDA). The final part of the analysis system is to run a separate evaluation program that follows the completion of each analysis. The new RTG_SST_HR shows a small consistent improvement over the original RTG_SST in the RMS errors against in-situ data. And there is a reduction of the day to day noise in the analyses, especially in the tropics. But, it is evident that the depiction of smaller scales of the analyses are limited because of the obstruction of clouds.

1. Introduction

The daily Real-time Global Sea Surface Temperature analysis (RTG_SST) was implemented on January 30, 2001 (Thiebaux *et al* 2003). The RTG_SST was developed as a daily blended analysis using in-situ and infrared measurement from one NOAA satellite (currently its NOAA-17) from the Advanced Very High Resolution Radiometer (AVHRR) SST data on a ½ degree (latitude, longitude) grid. At that time, atmospheric and ocean forecast modeling systems were being developed at higher-horizontal resolutions, so it was desirable that the sea surface temperature (SST) analyses used as surface boundary conditions should have higher-horizontal resolution. But initially, many of the existing SST analyses were based on coarse horizontal resolution (i.e., on a 1 X 1 degree latitude and longitude rectangular grid) with large time averages (1 week) The present RTG_SST has run reliably over the past six years, and has been used by the regional North American Model (NAM; Black 1994) at the National Centers for Environmental Prediction (NCEP) and by the global forecast model at the European Center for Medium Weather Forecasting (ECMWF).

Several studies have examined the RTG_SST and the results indicate that the higher resolution contributes to a positive improvement over lower resolution analyses. Chelton & Wentz (2005) have shown the RTG_SST depicts gradients of ocean features better than the lower resolution (time & space) Reynolds-Smith SST. In-situ data contributes a slight improvement when compared to another SST analysis at an even higher horizontal resolution, but ingesting only satellite SST. . Kara and Barron (2007) compared the RTG_SST to a similar analysis, the 1/8 Degree Modular Ocean Data Analysis System (MODAS) of the Naval Research Laboratory, using only AVHRR SST data. Their results showed the two SST analyses to be comparable. Unfortunately a common concern in these studies is the limitation of the accuracy of analyses based on AVHRR data because the AVHRR sensor can not see though clouds. So good cloud detection is critical for accurate retrievals, which is not always the case. In addition, the persistence of large areas of cloudiness is common property of weather systems (storms, fronts and hurricanes) over the ocean. The result is that many ocean areas can go long periods without being observed with AVHRR satellite data.

But the RTG_SST analysis has other limitations, due to its resolution (1/2 degree), in resolving the detailed temperature structure of ocean features (i.e. Gulf Stream), coastal zones bays and inland lakes. The NCEP's Global Forecast System (GFS) still uses the Reynolds-Smith SST (1994). Tests of the GFS using the RTG_SST showed that its forecast skill was slightly degraded, when compared to the GFS using the Reynolds-Smith SST. It was found that the RTG_SST day to day difference fields are noisy (as much as 0.5°C–1.0°C) which is likely due to degraded accuracy, inadequate cloud detection and irregular distribution of the various data sets. Satellite SST retrievals are processed by the U. S. Navy SST Shared Processing Center (SPC) at the Naval Oceanographic Office (May *et al*, 1998) and distributed to NCEP in near-real time. Those SST retrievals are based on regression equations which relate satellite brightness temperature to SST values by using drifting buoys (McClain *et al* 1985, Walton *et al* 1997).

But, because of the RTG_SST day to day noise, an alternative SST retrieval method was developed at NCEP through collaboration with the Joint Center for Satellite Data Assimilation (JCSDA). This SST retrieval algorithm is based on variational principles with a radiative transfer model(physical algorithm) which determines the SST increment to the SST first guess of the control variables using the previous day's SST analysis, the GFS model air temperature and mixing ratio (appendix 1). A cost function is defined to include: (1) control variables from the GFS and their first guess differences and (2) observed AVHRR radiances and the analyzed radiances. A derivation of the SST physical retrieval system is presented in the appendix by Li. The JCSDA physical retrievals show small positive improvements and a reduction of noise over the Navy regression derived SST.

A new higher resolution (RTG_SST_HR) analysis was developed and implemented September 27, 2005 for operational use at NCEP. The RTG_SST_HR runs on a 1/12 degree grid, by using *in situ* data and physical retrievals from both NOAA-17 and NOAA-18 satellite data (Gemmill, 2005). The original analysis package was upgraded to execute efficiently on multiple processors, rather than on one processor as in the original. The upgrade uses an MPI anisotropic recursive filter code (Purser *et al*, 2003) taken from the NCEP Grid-point Statistical Interpolation (GSI) analysis (Treadon *et al*, 2005). Table 1 presents a comparison of the original SST analysis system with the new upgraded system.

Table 1. A summary of the of the original and new daily SST analysis systems.

	RTG_SST	RTG_SST_HR
Implementation Date	January 31, 2001	September 25, 2005
Horizontal resolution	½ Degree latitude/longitude grid	1/12 Degree latitude/longitude grid
Satellite Data	NOAA 17 AVHRR	NOAA 17 & 18 AVHRR
Satellite Processing	Navy – Regression Retrievals	JCSDA – Physical Retrievals
***In situ* Data**	Fixed buoys, drifting buoys & ships	Fixed buoys, drifting buoys & ships
Correlation Length Scale	450 km to 100 km	450 km to 50 km.
AVHRR Limitations	Can not see through clouds	Can not see through clouds
IBM Code Configuation	Executes on one processor	Executes on multi-processors

In summary the major upgrades are:

1) Increased grid resolution to 1/12 degree,
2) Data from two satellites – NOAA 17 and 18,
3) SST generated by the JCSDA physical retrieval system.
4) Decrease in the minimum correlation length scale to 50km.
5) New 1/12 degree land-sea mask

2. Description of RTG_SST_HR

Examples of the RTG_SST and RTG_SST_HR analyses are presented in Figure 1a & 1b, and their anomalies in figures 2a & 2b. In general it is difficult to determine much in the way of differences between the two analyses, the influence of climatology dominates. . The SST patterns appear extremely similar. Differences are more apparent in the anomalies where the climatology is removed.

The algorithm (Parrish 2004) starts with a first-guess analysis, which is the previous day's SST analysis with a one day climate adjustment. *In-situ* observations for the last 24-h and high-resolution (8 km) satellite retrievals are ingested next. The SST data from moored buoys are averaged over the 24-h period; while SST reports from ships and drifting buoys are averaged separately within each $1/12^{\circ}$ x $1/12^{\circ}$ grid box over the last 24-h. The satellite SST retrievals are generated within NCEP by using the JCSDA physical retrieval algorithm (See appendix by Li). Satellite SST retrievals are corrected for their biases, before ingest into the analysis. This is based on creating an SST analysis on a 4 x 4 latitude, longitude grid using the previous 7 days of *in situ* data only (Reynolds & Smith, 1994, appendix). The satellite data bias correction for both the NAVY and JCSDA SST retrievals are shown in the panels in figure 3 a & b. Further the bias corrections are sub-divided by satellite retrievals: as day-time and night-time plot for each satellite (NOAA-17 and NOAA-18). It can be seen there is little concern for biases in the AVHRR SST based retrievals from either systems.

Where the satellite observes an ice cover exceeding 50 percent, the satellite derived SST values are rejected. The in-situ SST values are then computed from Millero's (1978) formula using the Levitus (1982) salinity climatology The determination for sea ice concentrations are determined by Grumbine (1996) by converting satellite data from the Special Sensor Microwave Imager (SSM/I) to sea ice concentrations.

The high-resolution SST analysis is an iterative minimum of a two dimensional variational interpolation analysis based on an SST first guess and SST observations (Thiebaux et al, 2003, Equation A1, appendix) . The analysis error correlation function R(d) is given by:

$R(d) = \exp(-d^2/\ell^2)$,

where d is the distance between data and analysis grid-point locations, and ℓ the analysis error length scale. Both d and ℓ are in km. The length scale ℓ varies from 50 to 450 km depending on the climatological SST temperature gradient (Smith & Reynolds, 1998) It is determined from the relation

$\ell = 225/|\mathrm{gradT}|$, and is within limits of $50\ \mathrm{km} < \ell < 450\ \mathrm{km}$

where gradT is the climatology temperature gradient.

From the above relations, ℓ is on the order of 50 km in high surface temperature gradient areas (I.e., Gulf Stream or Kuroshio) and on the order of 450 km in small gradient areas (i.e. Sargasso Sea).

Following the completion of the analysis, a separate verification program is run, which is described in the next section (3)

3. Evaluation of the RTG_SST_HR

The new RTG_SST_HR has been evaluated by comparing it with the RTG_SST. Since one of the problems of the original RTG_SST was there were large day to day differences "noise" in the analyses, the first concern was to compare the day to day SST analysis differences for each of the analyses (figures 4a & b). The physical retrievals reduced the day to day SST difference "noise", especially in the tropics. Further, the impact of satellite retrievals, produced by the Navy Shared Processing Center (SPC), and produced by the JCSDA, on its SST analysis shows that the physical retrievals also reduces the satellite SST biases. The next comparison was to determine the impact of higher resolution on the SST analysis in the Gulf Stream region, but thse results were disappointing as there was no difference. Again illustrating the problem of clouds over important ocean areas.

a) SST retrievals vs. drifting buoys

An evaluation of the satellite SST retrievals with drifting buoy data is shown for the global and Northwest Atlantic in Tables 2. a & b, respectively . The data are collocated by using the SST of the nearest buoy time to the SST satellite time in a 6 hour window and within a 50 km radius. There is almost no bias in any of the satellite retrievals with respect to the buoys, and the accuracy of the physical SST retrievals is slightly improved over those from the SPC as seen in the RMS error. Further, night time retrievals are only slightly better than the day time retrievals. The RMS errors are slightly higher over Northwest Atlantic, where ocean features with large temperature gradients dominate (i.e. the Gulf Stream and eddies).

Table 2.a) Global summary of the evaluation of SST retrievals from Navy SPC and JCSDA for satellites NOAA 18 & 17 using AVHRR data and separated for day and night using drifting buoys as ground truth for the period 2007/02/01 to 2007/06/23.

Satellite	Time	Mean Error	RMS Error
Shared Processing Center (regression retrievals)			
NOAA 18	Day	-0.01	0.42
	Night	0.03	0.46
NOAA 17	Day	-0.03	0.45
	Night	-0.04	0.42
Joint Center for Satellite Data Assimilation (physical retrievals)			
NOAA 18	Day	-0.03	0.41
	Night	0.07	0.36
NOAA 17	Day	0.07	0.40
	Night	0.03	0.36

Table 2.b) Northwest Atlantic (Gulf Stream) Regional summary

Satellite	Time	Mean Error	RMS Error
Shared Processing Center (regression retrievals)			
NOAA 18	Day	0.12	0.62
	Night	-0.03	0.54
NOAA 17	Day	0.08	0.62
	Night	0.00	0.47
Joint Center for Satellite Data Assimilation (physical retrievals)			
NOAA 18	Day	0.03	0.52
	Night	0.10	0.46
NOAA 17	Day	0.11	0.48
	Night	0.08	0.42

b) SST analyses vs. drifting buoys

An evaluation of the satellite SST retrievals with drifting buoy data is shown in Table 3. In reality, the statistics are almost the same for the globe ocean, but the RTG_SST_HR are slightly worse over the North West Atlantic (Gulf Stream). It is suspected that the correlation length scales need to be tuned for coastal regions and mesoscale ocean features (Gulf Stream).

Table 3. Summary of the evaluation of the two analysis systems: RTG_SST & RTG_SST_HR for global and the Northwest Atlantic (Gulf Stream)for the mean bias, and mean RMS against drifting buoys for the period from January 1, 2007 to June 29, 2007

Global	RTG_SST Operational (1/2D)	-0.02	0.56
	RTG_SST_HR JCSDA Retrievals (1/12D)	0.01	0.55
Gulf Stream	RTG_SST Operational (1/2D)	-0.08	0.86
	RTG_SST_HR JCSDA Retrievals (1/12D)	-0.02	0.72

c) On-line SST daily monitoring system

A verification program is executed for both versions of the operational SST analysis following the completion of the analysis itself. The verification statistics are generated by rerunning the analysis programs five times, each time withholding an independent subset of the pre-selected buoys (about 20%), and evaluating the resulting analysis at the locations of the withheld data. The bias and root-mean-square (RMS) difference between the independent buoys and the analysis are computed for each subset. These statistics are presented daily for the global and a few selected sub-regions. In-situ data coverage for one day are presented in figure 6 For example, daily validation statistics for the Equatorial zone (30S – 30N) and the Northwest Atlantic region are presented in figures 7 a & b and 8 a & b respectively. The biases are small, and the RMS differences are slightly but consistently better for the RTG_SST_HR than the RTG_SST.

4. Further Tuning for RTG_SST_HR Analysis

Now that the RTG_SST_HR has been running successfully in operations, there are number of experiments to carry out to determine their impact on improving the analysis.

The first set of these experiments have to do with are *tuning* the analysis. These experiments include:

1) New high resolution Pathfinder climatology
2) Analysis error correlation length scales for the 1/12 degree grid,
3) Error assignments for each SST data source and the background field,
4) An-isotropic correlation length scales, which are important along zones of large SST gradients and along coast lines,

There second set of experiments to be carried out, those include the use of additional satellite systems:

1) AMSR SST retrievals
2) GOES SST retrievals

It is clear that both analysis systems are somewhat limited because of the interference of clouds in the AVHRR retrievals. An analysis can go long periods of time without updating by satellite observations. There is another sensor, however that has nearly all-weather (except for rain) capability aboard the AMSR satellite, although its horizontal resolution is much coarser than the AHHRR and has been experimental until recently. The AVHRR retrievals have been well accepted as operational for over 20 years. Experiments for blending these two sets of satellite retrievals. shall be carried out. In fact , Reynolds et. al.(2007) has recently successfully generated improved SST analyses using both data sets on ¼ degree latitude, longitude.. There is further another sensor aboard the GOES satellites that provides SST data similar to the AVHRR, but provides hourly looks at the ocean, so that it daily coverage is less limited by clouds. But, the data are limited to Western Hemisphere oceans, (bounded by 60S to 60N and 180W to 30W) adjacent to the United States Analyses combining GOES and AVHRR SST data shall also be made.

5. Acknowledgements:

Thanks are given to Avichal Mehra and Vladimir Krasnopolosky of MMAB for their review of this paper.

References

Black, T. L. (1994): The New NMC mesoscale Eta model: Description and forecast examples. *Wea. Forecasting*, **9**, 265-278.

Chelton, Dudley B., and Frank J. Wentz (2005): Global Microwave Satellite Observations of Sea-Surface Temperature for Numerical Weather Prediction and Climate Research, *Bull. AMS*, **86**, 1097-1115.

Gemmill, William (2005): New JCSDA physical retrieval of sea surface temperature used in upgraded operational sst analysis. JCSDA Quarterly, No. 12 :

Grumbine, R W (1996): Automated passive microwave sea ice concentration analysis at NCEP. OMB Tech Note 120, NCEP/Environmental Modeling Center, Camp Springs, MD, 13 pp.

Kara, A.B and C.N. Barron (2007): Fine resolution satellite based daily sea surface temperature over the global ocean. J. Geophys Res, **112**,C05041, 16 pp

Levitus, S. (1982): Climatological atlas of the world. *NOAA Professional Paper 13*, 173 pp.

May, Douglas A, Michelle M. Parmeter, Daniel S. Olszeski, and Bruce D. McKenzie (1998): Operational Processing of Satellite Sea Surface Temperature Retrievals at the Naval oceanographic Office, *Bull. AMS*, **79**, 397-407.

McClain, E. P., W. G. Pichel and C. C. Walton (1985): Comparative performance of AVHRR-based multichannel sea surface temperatures *Geophysical Research*, **90**, 587-11,601.

Millero, F.J., (1978): Freezing point of seawater. Eighth Report of the Joint Panel on Oceanographic Tables and Standards, *UNESCO Tech. Pap . Mar. Sci.* No. 28, Annex **6**, UNESCO, Paris.

Parrish, DF (2004): Personnel communications.

Purser, R.J., W.S. Wu, D.F. Parrish and N.M. Roberts, (2003): Numerical aspects of the application of recursive filters to variational statistical analysis; Part II: Spatially inhomogeneous and anisotropic general covariances. *Mon Wea Rev*, **191**, 1536-1548

Reynolds, Richard, W. and Thomas M. Smith (1994): Improved Global Sea Surface Temperature Analyses Using Optimum Interpolation, *J of Climate*, **7**, 929-948.

Reynolds, Richard, Thomas M Smith, Chunying Liu, Dudley H Chelton, Kenneth S Casey and Michael G. Schlax and Dudley (2007): Daily High-Resolution blended analyses for sea surface temperature: J of Climate:

Smith, T.M. and R.W. Reynolds (1998): A high-resolution global sea surface temperature climatology for the 1961-1990 base period, J. Climate, **11**, 3320-3323.

Thiebaux J, Eric Rogers, Wanqiu Wang and Bert Katz (2003): A New High-resolution Global Sea Surface Temperature Analysis, *Bull. AMS*, **84**, 645-656.

Treadon, Russell, (2005): First GSI User Orientation, 4-5 Jan 2005, WWB, Camp Springs, MD. [http://www.emc.ncep.noaa.gov/gbm/treadon/gsi/]

Walton, CC, WG Pichel, and JF Sapper (1998): The Development and Operational application of Nonlinear algorithms for the Measurement of Sea Surface Temperatures with the NOAA Polar-orbiting Environmental Satellites, *J. Geophys. Res.*, **103**,

Appendix 1

Sea Surface Temperature (SST) Physical Retrieval Algorithm

By Xu Li (Joint Center for Satellite Data Assimilation)

A.1. Formulation

The basic principle of the physical (or variational) SST retrieval algorithm is to find out the increment to the first guess of the control variables, which may contribute to the radiative transfer, by minimizing a cost function which measures the distances between (1) The analyzed control variable and its first guess and (2) observed radiance and the analyzed (modeled) radiance

.

Generally, the variational assimilation or retrieval problem is to minimize the following cost function:

$$J = J_b + J_o = \underbrace{\frac{1}{2}(X^a - X^f)^T B^{-1}(X^a - X^f)}_{(1)} + \underbrace{\frac{1}{2}[y - H(X^a)]^T O^{-1}[y - H(X^a)]}_{(2)} \quad \text{(a1.1)}$$

Here, ^{a},^{o},^{f} represents analysis, observation and first guess respectively. X is the vector of control variables, y is the observation vector. B , O is the error covariance matrix of the X^f and y respectively. H is the .observation operator, which can be the interpolation operator or radiative transfer model. ^{T} means transpose.

A radiative transfer model is required to simulate the first guess radiance and written as:

$$T_{b,c}^f = H_c[T_s^f, T_k^f, Q_k^f] \quad \text{(a1.2)}$$

Here, T_k^f and Q_k^f is the first guess (6-hour forecast) of the atmospheric temperature and water vapor mixing ratio, respectively, for model layer $k = 1, L$.

T_s^f is the first guess of the SST retrieval (previous SST analysis here). c is the satellite instrument (AVHRR) channel index. $T_{b,c}$ is brightness temperature of channel c.

Generally, for channel c, the analysis increment of T_b from T_b^f can be written as:

$$\delta T_{b,c} = T_{b,c}^a - T_{b,c}^f = \frac{\partial T_{b,c}}{\partial T_s} \cdot \delta T_s + \sum_{k=1}^{L} \left(\frac{\partial T_{b,c}}{\partial T_k} \cdot \delta T_k \right) + \sum_{k=1}^{L} \left(\frac{\partial T_{b,c}}{\partial Q_k} \cdot \delta Q_k \right), \text{ where} \tag{a1.3}$$

$$\delta T_s = T_s^a - T_s^f, \delta T_k = T_k^a - T_k^f, \delta Q_k = Q_k^a - Q_k^f.$$

The derivatives $\frac{\partial T_{b,c}}{\partial T_s}$, $\frac{\partial T_{b,c}}{\partial T_k}$ and $\frac{\partial T_{b,c}}{\partial Q_k}$ are available from the radiative transfer model and represent the sensitivity of the radiances to the analysis variables. To simplify the problem, it is assumed that δT_k and δQ_k are not dependent on altitude (k) and are written as δT_a and δQ_a, respectively, this gives:

$$\delta T_{b,c} = T_{b,c}^a - T_{b,c}^f = \frac{\partial T_{b,c}}{\partial T_s} \cdot \delta T_s + \frac{\partial T_{b,c}}{\partial T_a} \cdot \delta T_a + \frac{\partial T_{b,c}}{\partial Q_a} \cdot \delta Q_a, \text{ where} \tag{a1.4}$$

$$\frac{\partial T_{b,c}}{\partial T_a} = \sum_{k=1}^{L} \frac{\partial T_{b,c}}{\partial T_k}, \quad \frac{\partial T_{b,c}}{\partial Q_a} = \sum_{k=1}^{L} \frac{\partial T_{b,c}}{\partial Q_k}.$$

Therefore, T_s, T_a and Q_a become the control variables of the variational retrieval problem. There are no explicit expressions for T_a^f, Q_a^f. However δT_a, δQ_a share the increments caused by the difference between the observed ($T_{b,c}^a$) and simulated ($T_{b,c}^f$) radiances in the retrieval process. This is required to account for the attenuation of the radiances by atmosphere.

Let $\sigma_s, \sigma_a, \sigma_q$ be the error of T_s, T_a and Q_a. Let $\sigma_{b,c}$ be the error of the simulated radiance for channel c. The retrieval is done for each datum, the errors of first guess and observation are assumed to be uncorrelated. Therefore,

$$X = \begin{pmatrix} T_s \\ T_a \\ Q_a \end{pmatrix}, \quad y = \begin{pmatrix} T_{b,3} \\ T_{b,4} \\ T_{b,5} \end{pmatrix}, \quad B = \begin{pmatrix} \sigma_s^2 & 0 & 0 \\ 0 & \sigma_a^2 & 0 \\ 0 & 0 & \sigma_q^2 \end{pmatrix}, O = \begin{pmatrix} \sigma_{b,3}^2 & 0 & 0 \\ 0 & \sigma_{b,4}^2 & 0 \\ 0 & 0 & \sigma_{b,5}^2 \end{pmatrix}$$

Where X represents variables of X^a and X^f

Therefore, the cost function becomes

$$J = \frac{1}{2\sigma_s^2}(\delta T_s)^2 + \frac{1}{2\sigma_a^2}(\delta T_a)^2 + \frac{1}{2\sigma_q^2}(\delta Q_a)^2 + \frac{1}{2}\sum_c \frac{1}{\sigma_{b,c}^2}[T_{b,c}^o - (T_{b,c}^f + \delta T_{b,c})]^2 \tag{a1.5}$$

$J = J_{\min}$ when $\frac{\partial J}{\partial T_s} = \frac{\partial J}{\partial T_a} = \frac{\partial J}{\partial Q_a} = 0$, this gives three linear equations with three unknowns:

$$\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} \delta T_s \\ \delta T_a \\ \delta Q_a \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix} \tag{a1.6}$$

Let $w_s = \frac{1}{\sigma_s^2}, w_a = \frac{1}{\sigma_a^2}, w_q = \frac{1}{\sigma_q^2}$, $w_c = \frac{1}{\sigma_{b,c}}, S_c = \frac{\partial T_{b,c}}{\partial T_s}, A_c = \frac{\partial T_{b,c}}{\partial T_a}, Q_c = \frac{\partial T_{b,c}}{\partial Q_a}, T_c = T_{b,c}^o - T_{b,c}^f$ for AVHRR nighttime retrievals with channel $c = 3, 4, 5$,then

the solution of (a1.5) gives three increments; only δT_s is used to obtain the SST retrieval.
The errors used in the retrieval scheme are as follows:

1) Day-time, $\sigma_s = 0.5, \sigma_a = 1.2, \sigma_q = 0.95 \times \{\max[(T_s^f - 273.16) \times 0.03, 0.0]\}$
2) Night-time, $\sigma_s = 0.45, \sigma_a = 0.9, \sigma_q = 0.65 \times \{\max[(T_s^f - 273.16) \times 0.03, 0.0]\}$
3) NOAA-16, $\sigma_{b,3} = 0.12, \sigma_{b,4} = 0.16, \sigma_{b,5} = 0.18$;
4) NOAA-17, $\sigma_{b,3} = 0.11, \sigma_{b,4} = 0.17, \sigma_{b,5} = 0.19$.

A.2 AVHRR Radiance Bias Correction

A bias correction is applied to the AVHRR radiance dynamically based on 2-week observed and simulated radiances with a look-up table in which the correction amount depends on the SST value.

A.3 Quality Control

Initially if the difference between the observed and the modeled radiance exceeds a threshold value for a given channel, the radiance datum is discarded and not used. The threshold of rejection is given by:

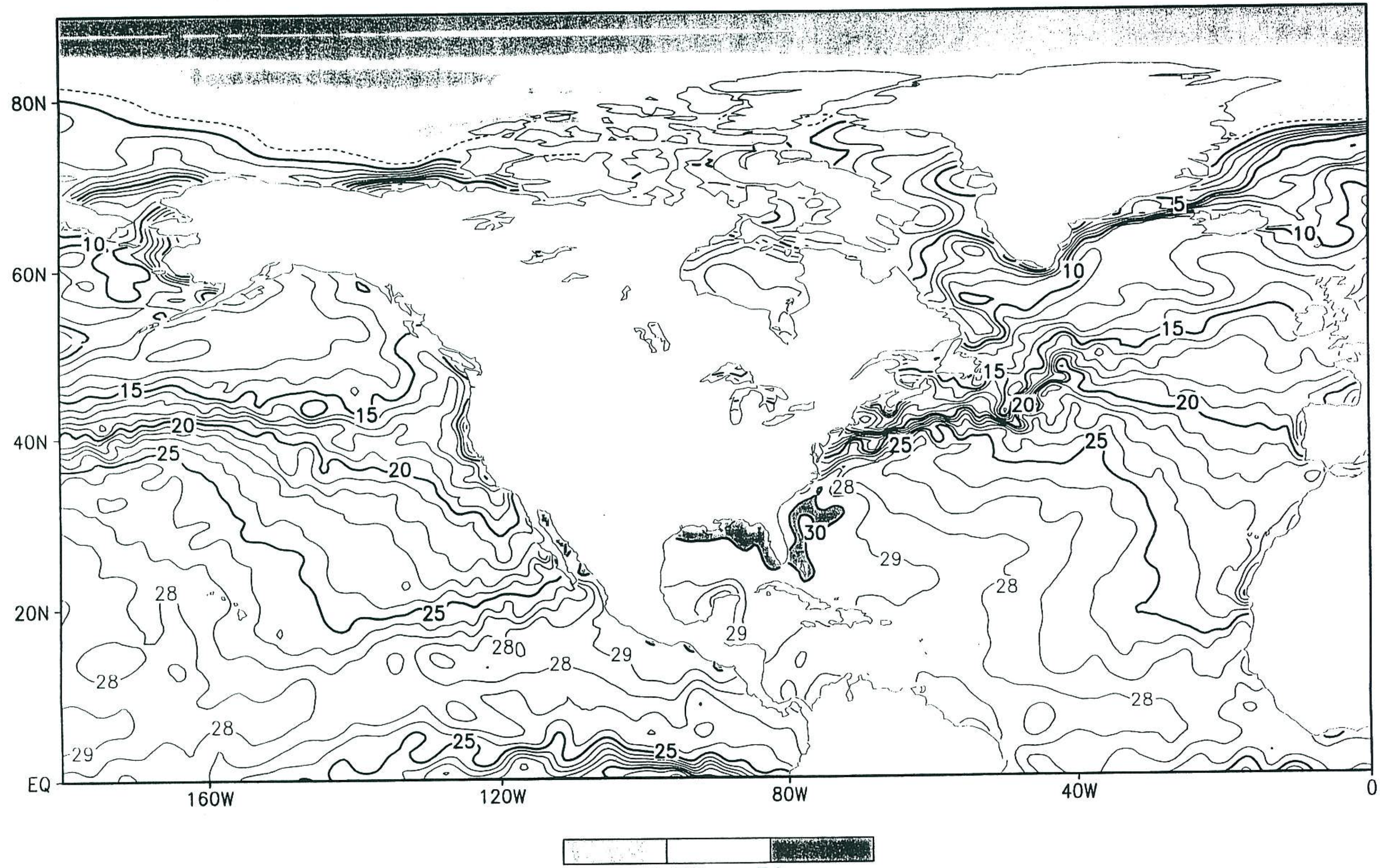
$$abs(T_{b,c}^o - T_{b,c}^f) > 10.0 \times \sigma_{b,c},$$

List of Figures:

Figure 1 a&b
Global SST analyses (2)

The global daily RTG_SST (1/2 Degree latitude, longitude) analysis & the RTG_SST_HR (1/12 Degree latitude , longitude) analysis for 28 August 2007

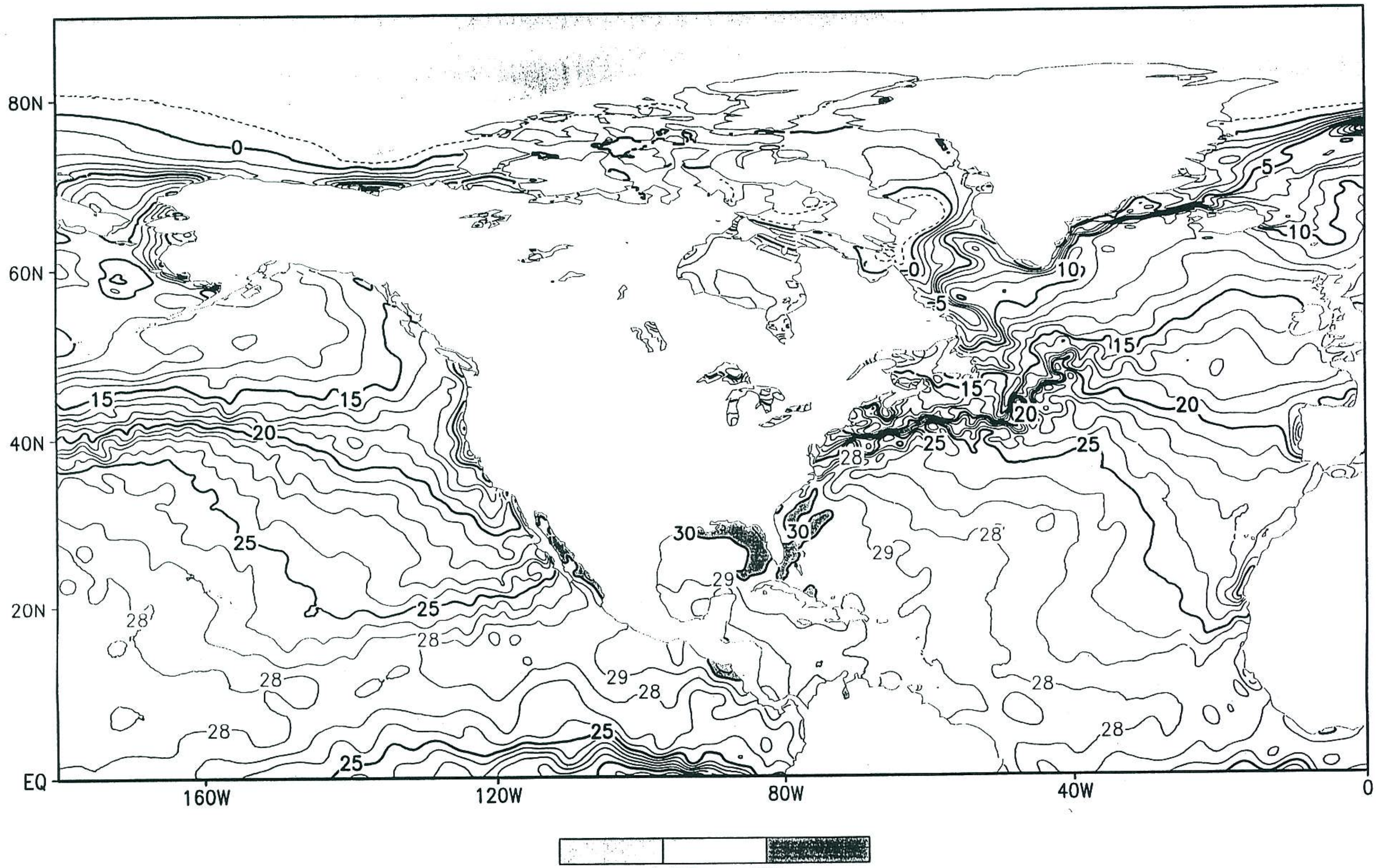
OPER RTG_SST Analysis (0.5 deg) for 28 Aug 2007



2D-VAR OPER

18:49:18 TUE AUG 28 2007

OPER H.R. RTG_SST Analysis (0.083 deg) for 28 Aug 2007



2D-VAR OPHI

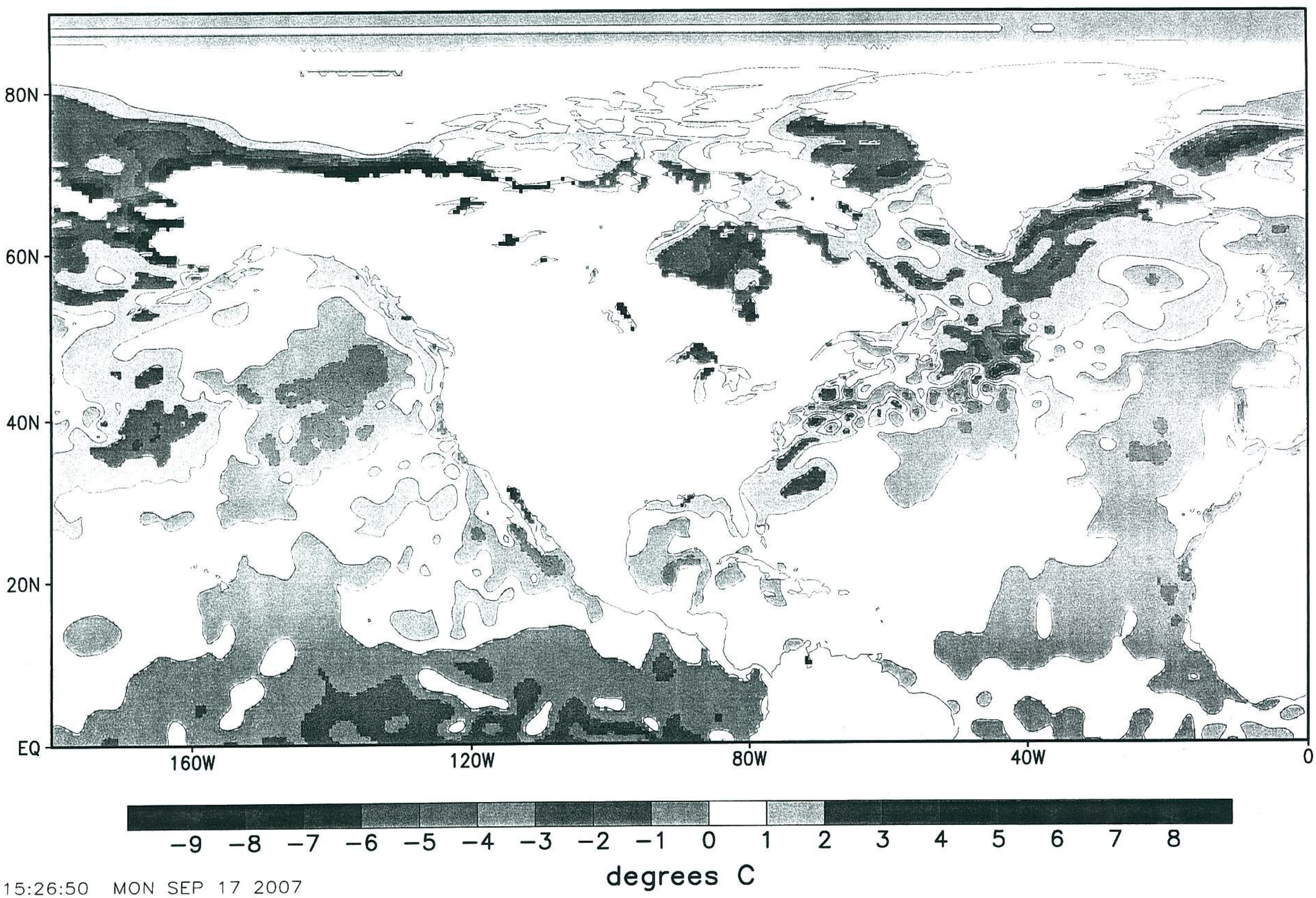
19:06:17 TUE AUG 28 2007

Figure 2 a & b
Global SST anomaly (2)
RTG_SST (1/2D) & RTG_SST_HR (1/12D)

The global daily RTG_SST anomaly (1/2 Degree latitude, longitude) & the RTG_SST_HR (1/12 Degree latitude , longitude) anomaly for 28 August 2007

NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch

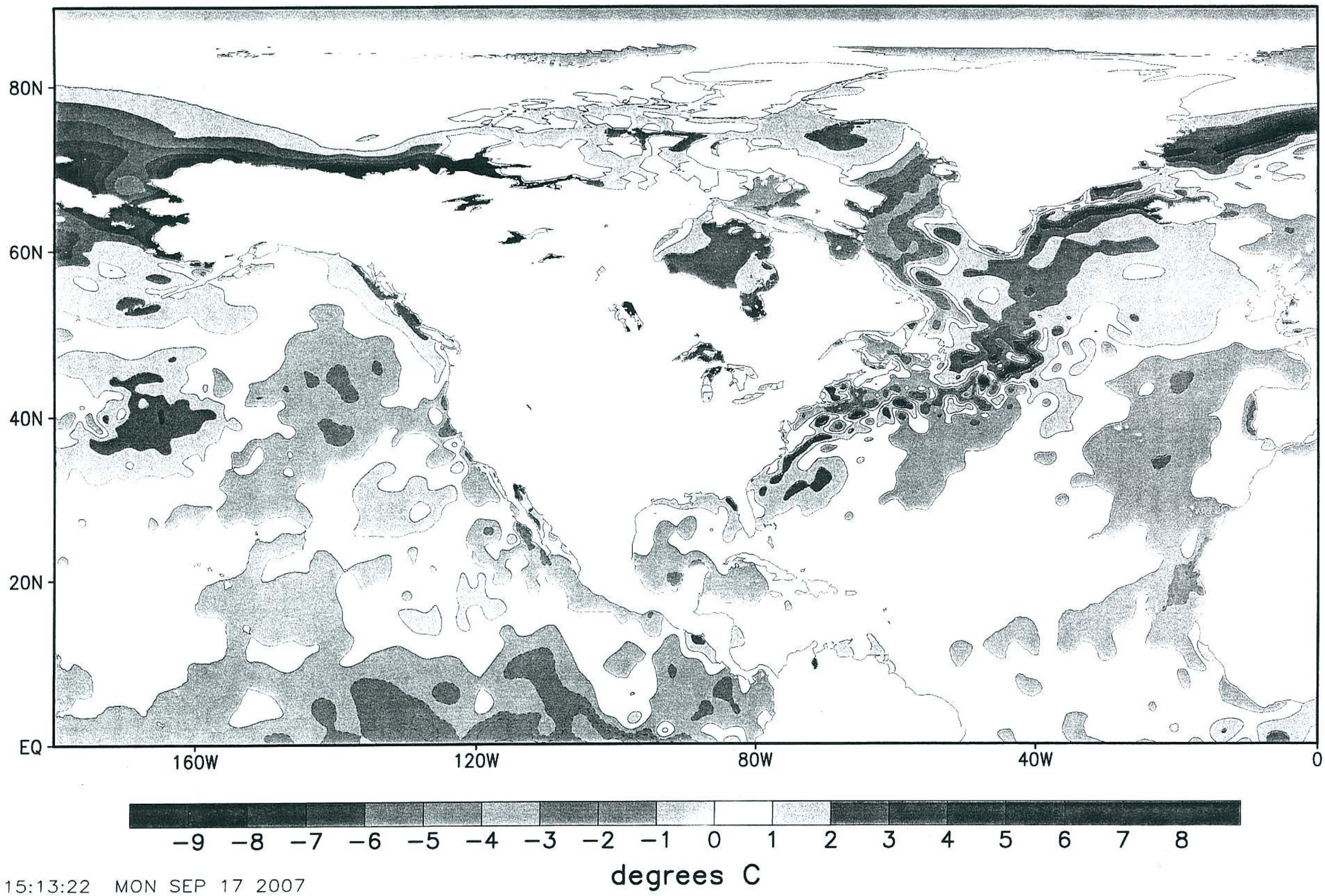
RTG_SST Anomaly (0.5 deg X 0.5 deg) for 28 Aug 2007



15:26:50 MON SEP 17 2007

NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch Oper H.R.

RTG_SST Anomaly (0.083 deg X 0.083 deg) for 28 Aug 2007



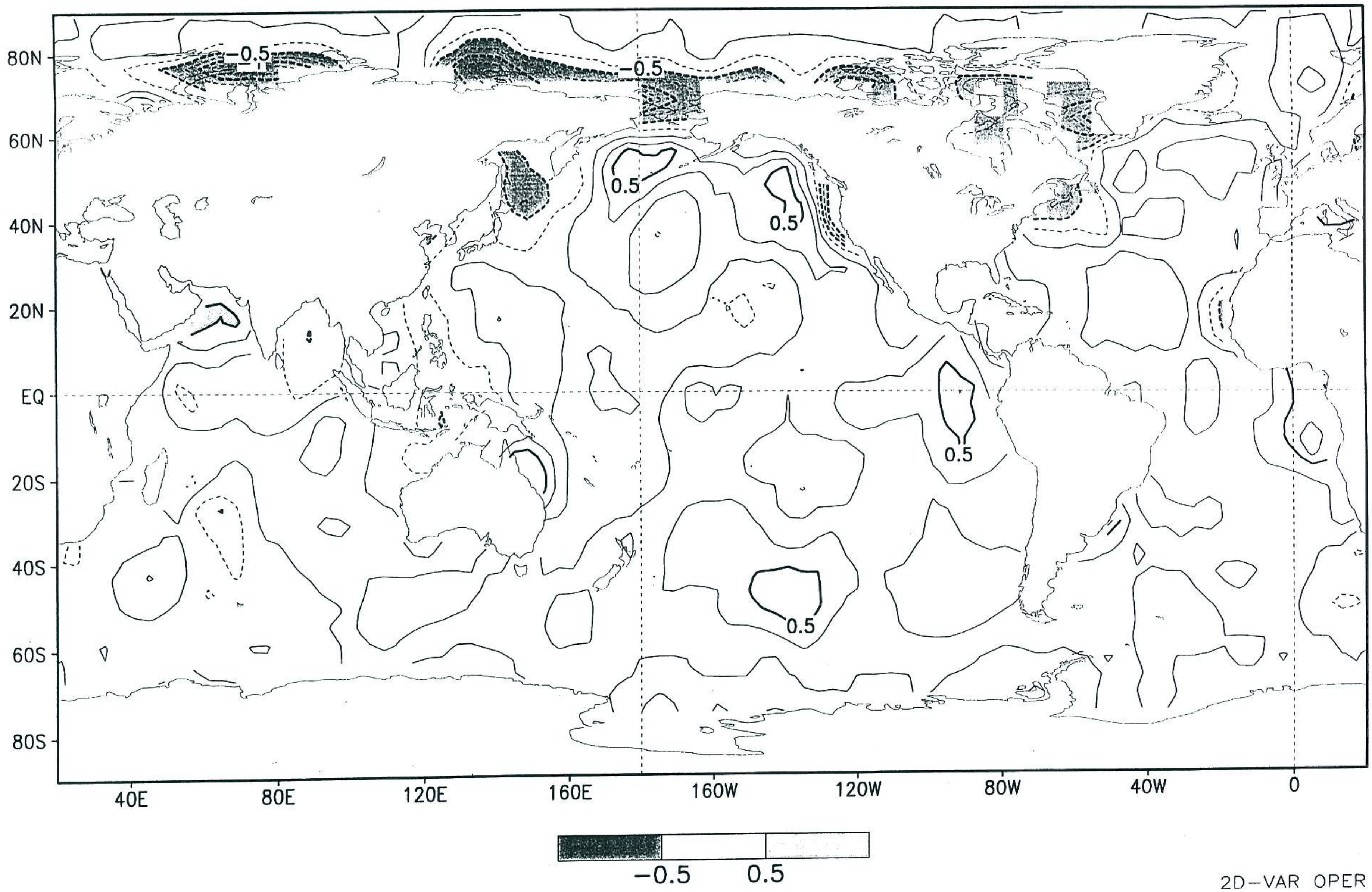
15:13:22 MON SEP 17 2007

Figure 3 a & b

Sat bias corrections for (6)

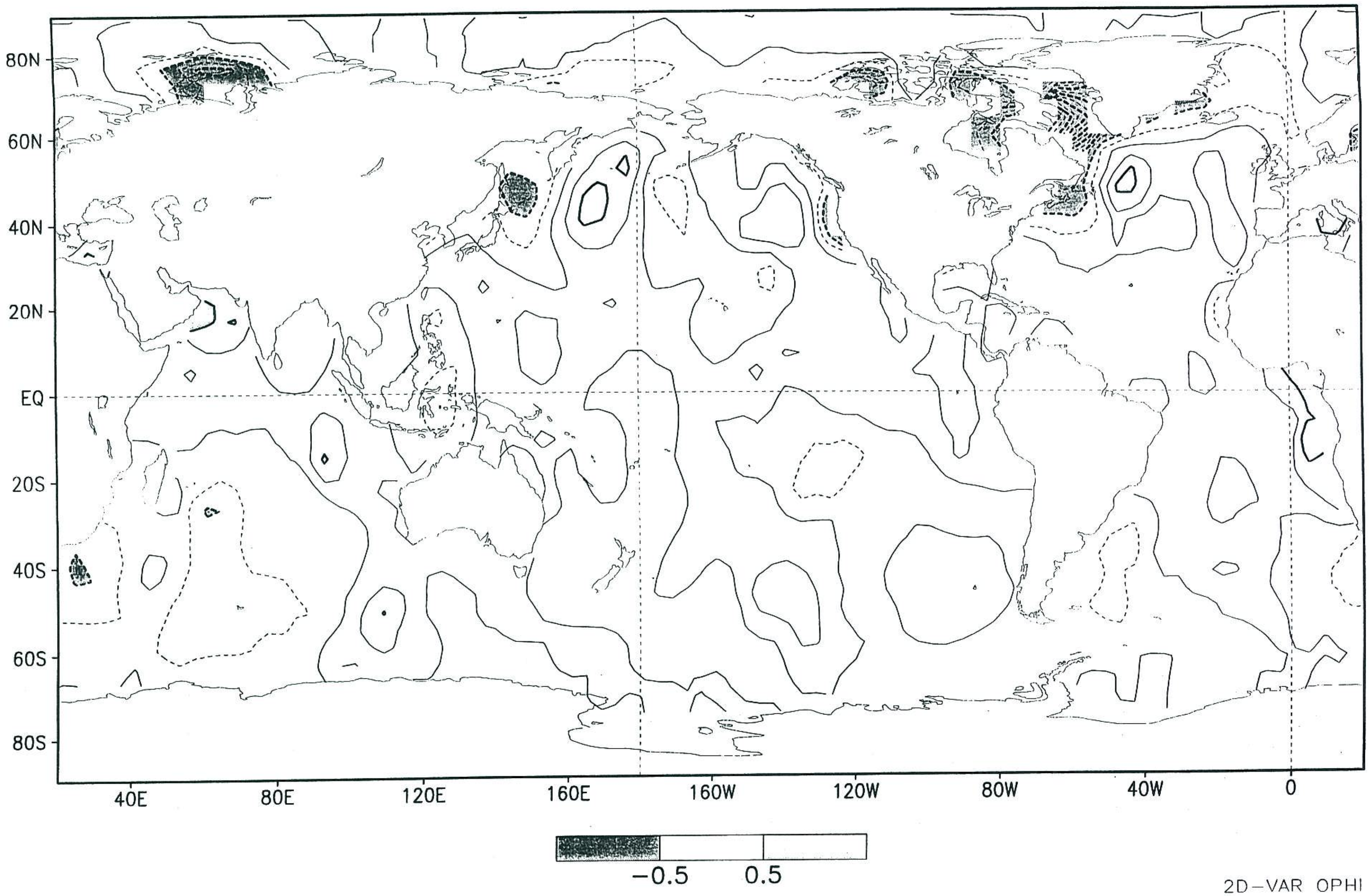
The global day and night NOAA-17 (NAVY) satellite retrieval bias corrections and the NOAA-17 & NOAA 18 (JCSDA) satellite retrievals bias corrections for 28 August 2007

Nighttime NOAA-17 Satellite Bias Correction for 28 Aug 2007



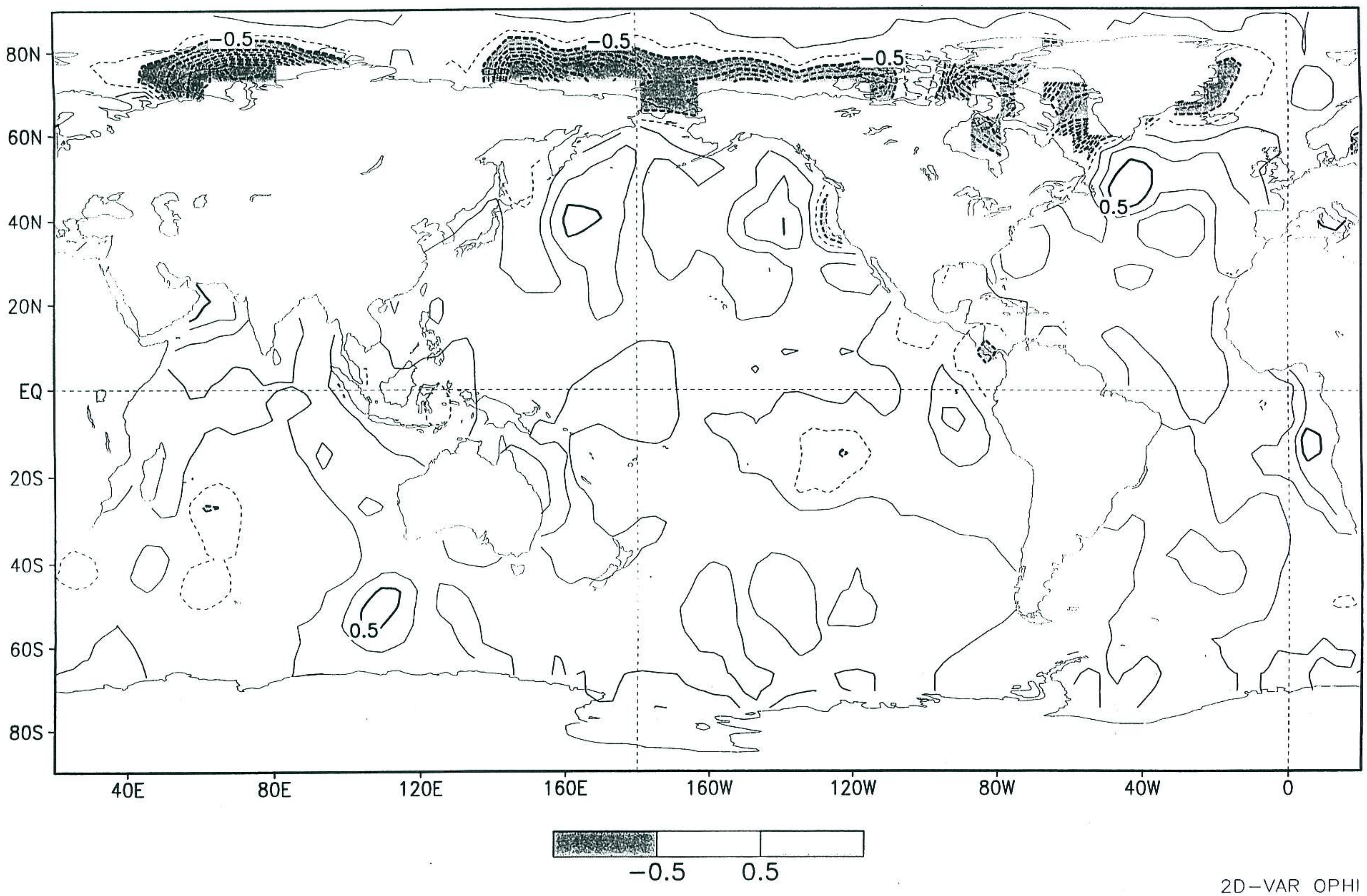
19:23:51 TUE AUG 28 2007

Nighttime NOAA-17 Satellite Bias Correction for 28 Aug 2007



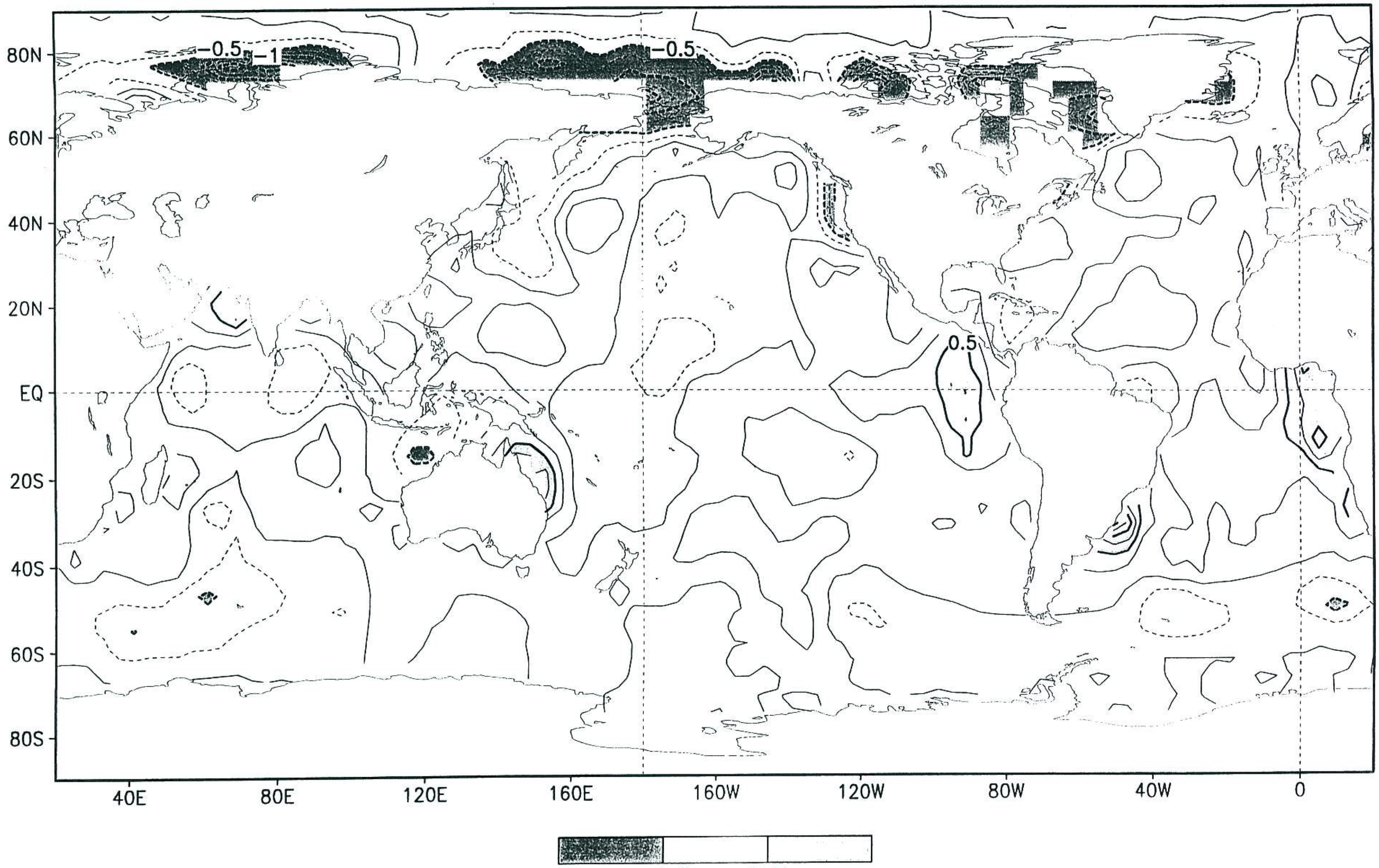
19:07:16 TUE AUG 28 2007

Daytime NOAA-17 Satellite Bias Correction for 28 Aug 2007



19:07:16 TUE AUG 28 2007

Daytime NOAA−17 Satellite Bias Correction for 28 Aug 2007

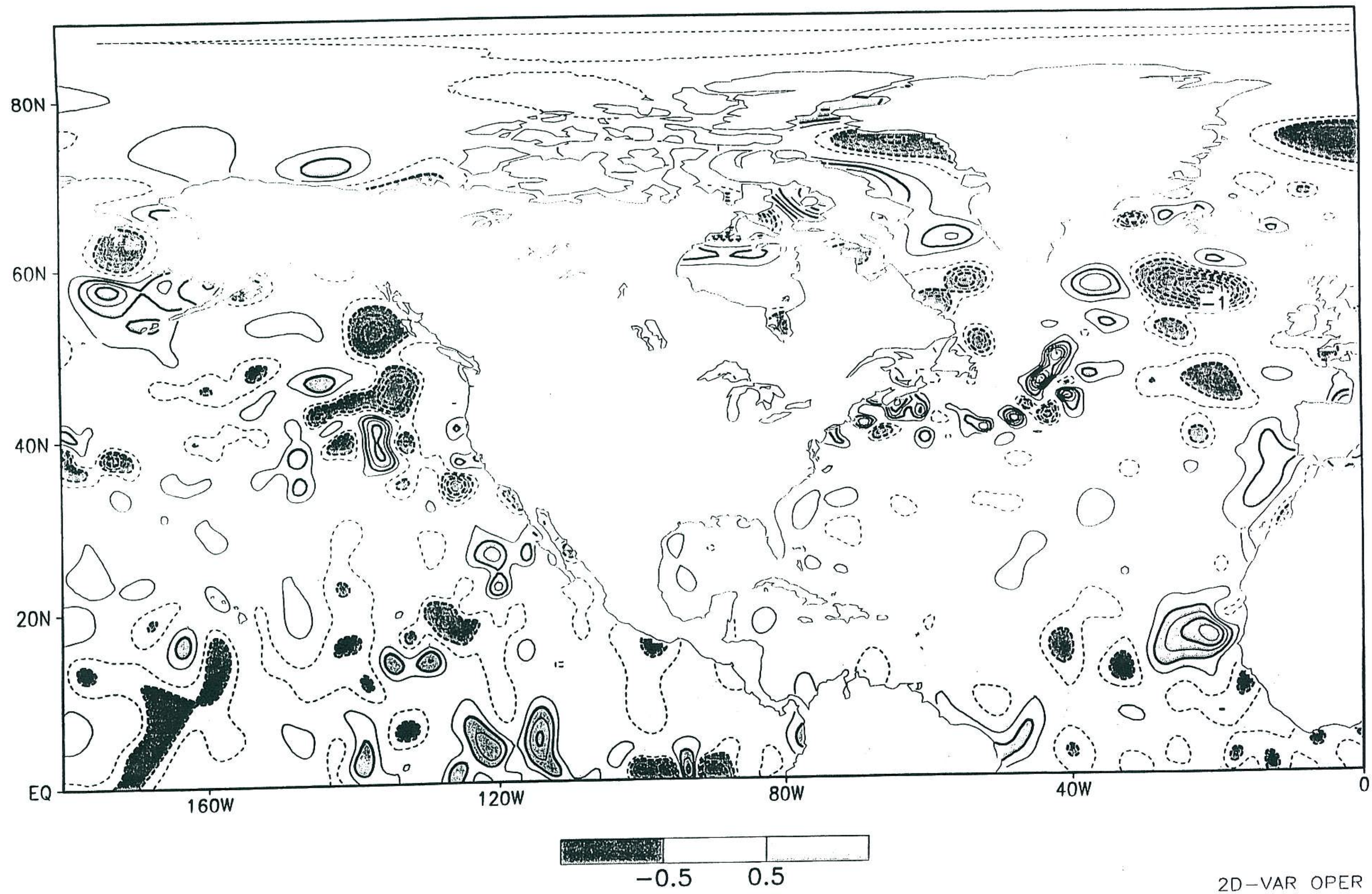


19:23:51 TUE AUG 28 2007

Figure 4 a & b

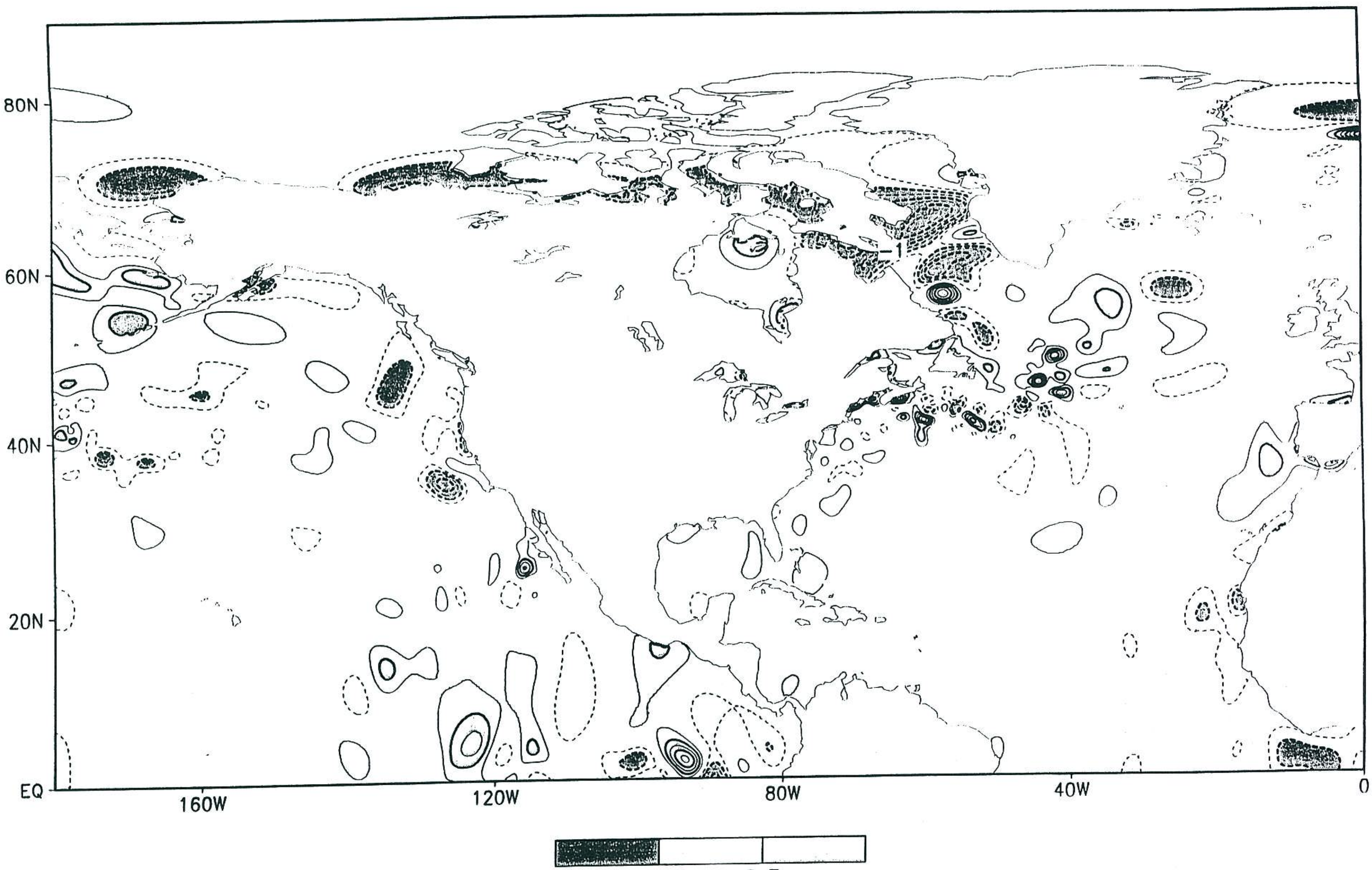
The day to day global SST difference for the RTG_SST analyses and for the RTG_SST_HR analyses on August 28,2007.

RTG_SST (Today) - RTG_SST (Yesterday) (0.5 deg) 28 Aug 2007



18:49:47 TUE AUG 28 2007

RTG_SST (Today) - RTG_SST (Yesterday) (0.083 deg) 28 Aug 2007

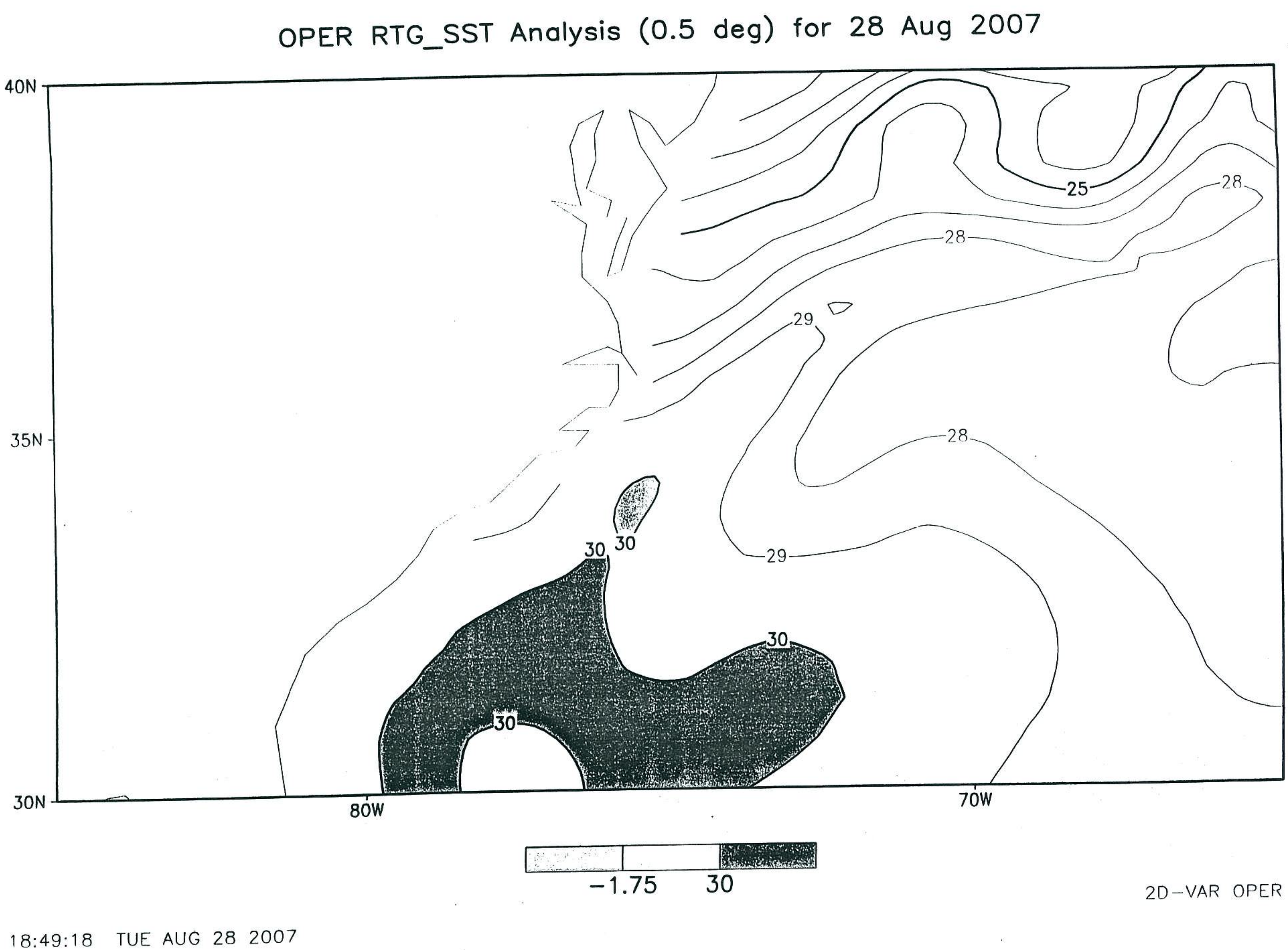


19:06:25 TUE AUG 28 2007

Figure 5 a & b

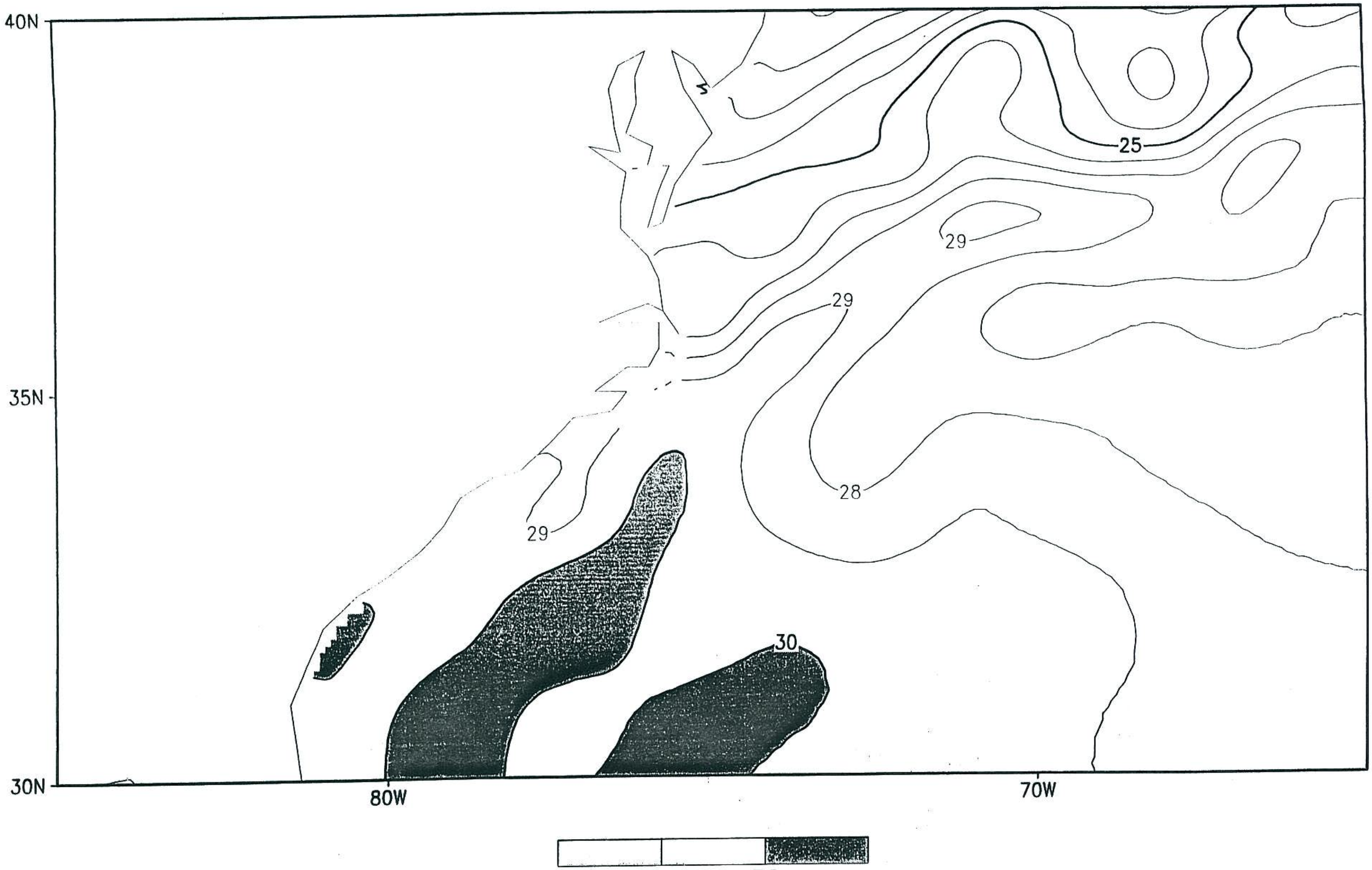
An expanded view of the SST analyses in the Northwest Atlantic for the Gulf Steam. For the

RTG_SST & RTG_SST_HR for August 28, 2007



OPER RTG_SST Analysis (0.5 deg) for 28 Aug 2007
40N
35N
30N
80W
70W
25
28
28
28
29
29
30
30
30
30
-1.75
30
2D-VAR OPER
18:49:18 TUE AUG 28 2007

OPER H.R. RTG_SST Analysis (0.083 deg) for 28 Aug 2007



2D-VAR OPHI

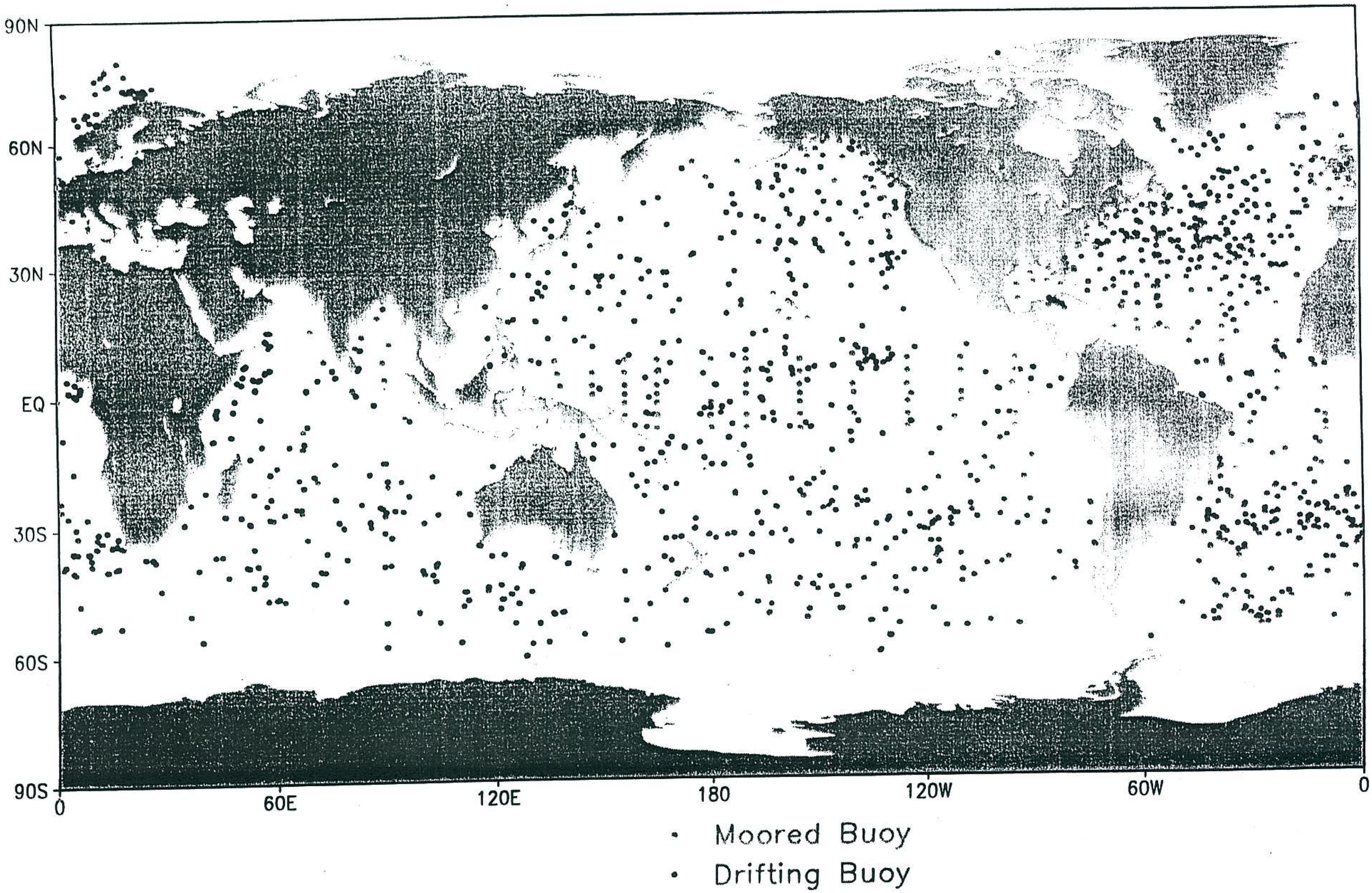
19:06:29 TUE AUG 28 2007

Figure 6

Ocean surface data distribution for:one day of coverage for ship and buoy observations for August 28, 2007

NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch

ENSEMBLE VERIFICATION: Buoy Distribution for 28 Aug 2007

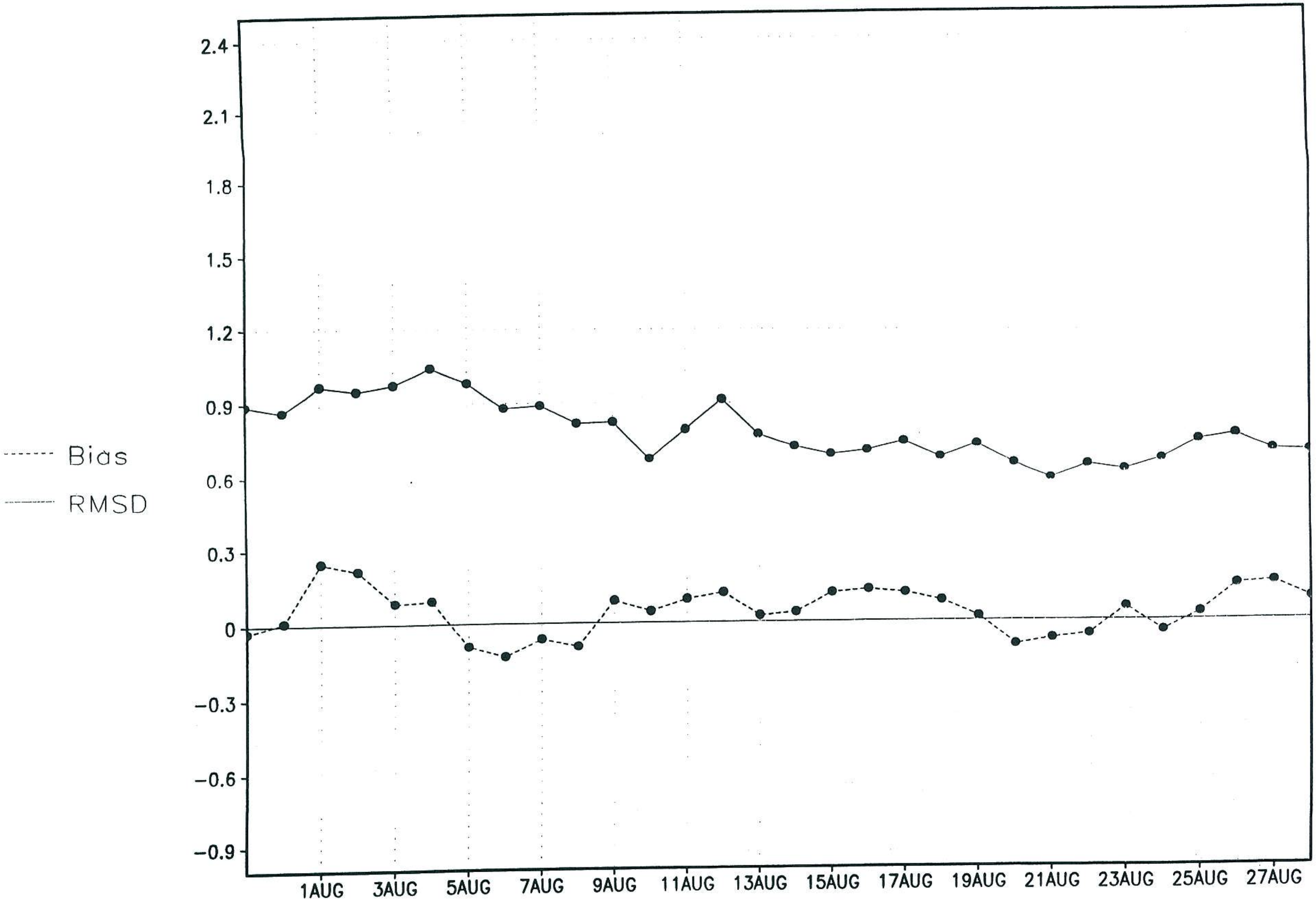


18:49:12 TUE AUG 28 2007

Figure 7 a & b

Daily validation plots of the RTG_SST & RTG_SST_HR for 30 days; 29 July – 27 August, 2007
The validation ais a rerun of the analysis 5 times with holding a different 1/5 set of the insitu data.
for the oceans in the tropical zone of 30S – 30N, and 180W – 180E and the Northwest Atlantic Ocean 30N - 45N and 80W – 40 W . Dased line is bias and the solid line is the RMS. .

NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch
ENSEMBLE VERIFICATION: RTG_SST–minus–buoy Statistics

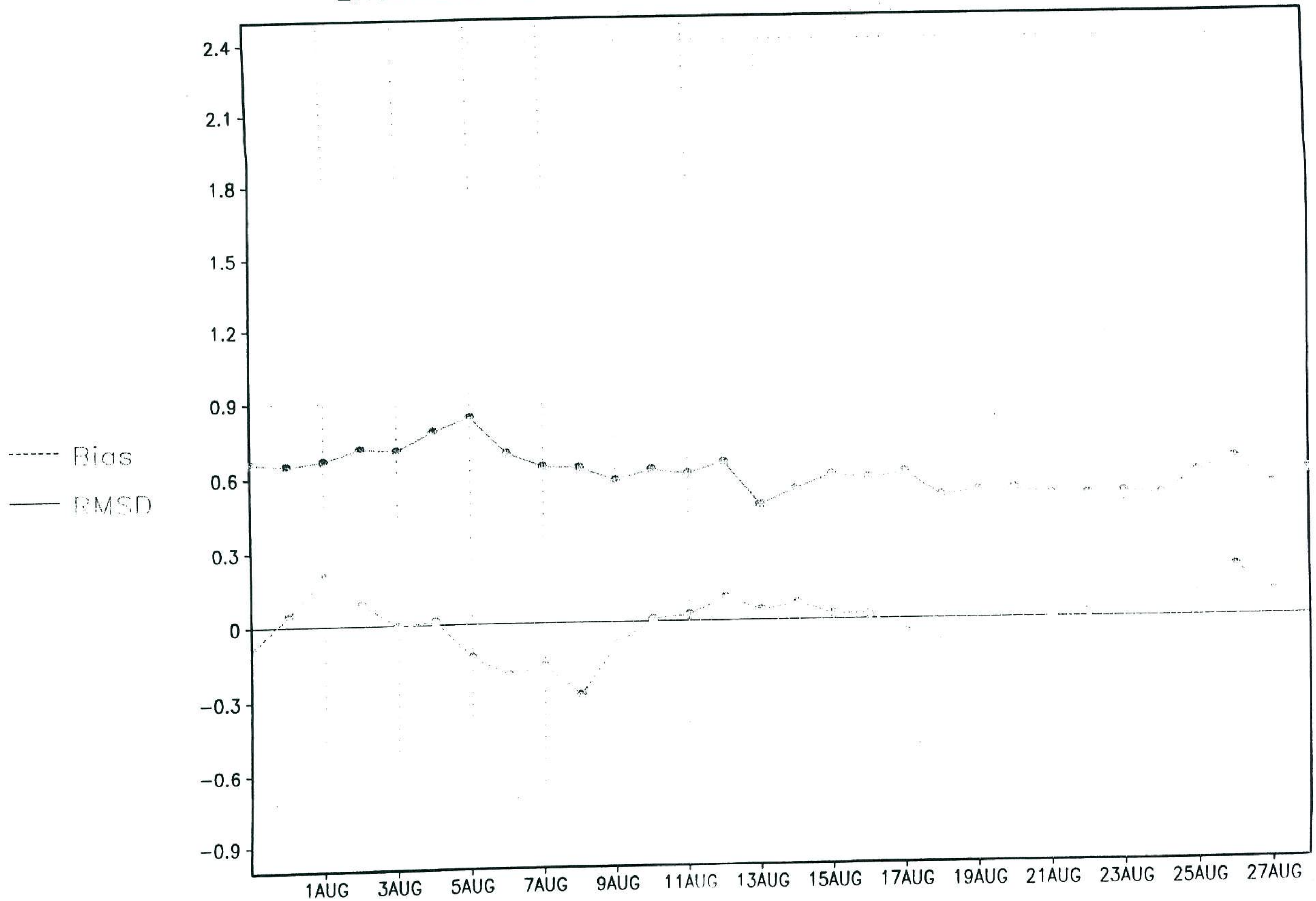


Lat: 30N – 45N Lon: 80W – 40W

18:49:18 TUE AUG 28 2007

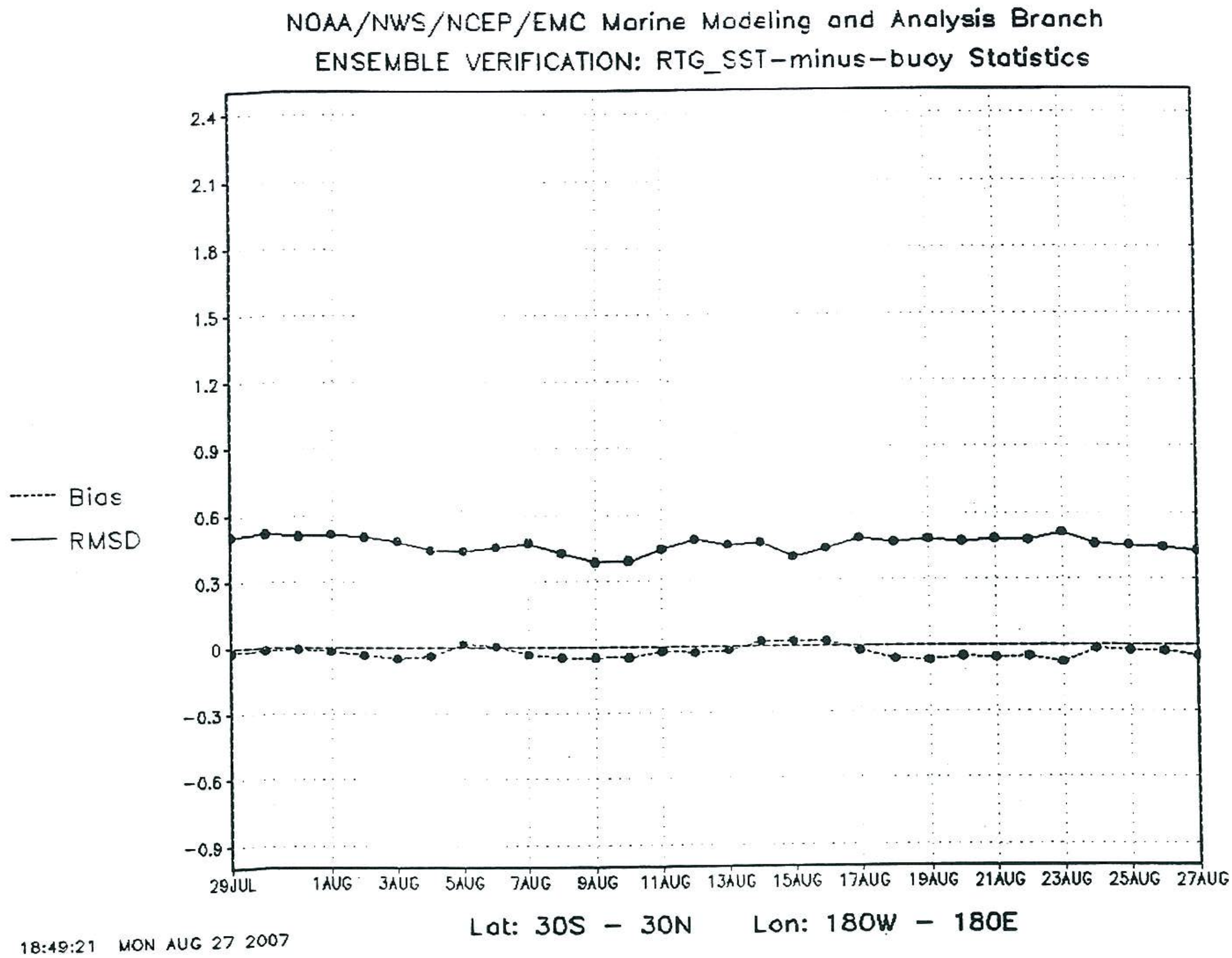
NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch Oper H.R.

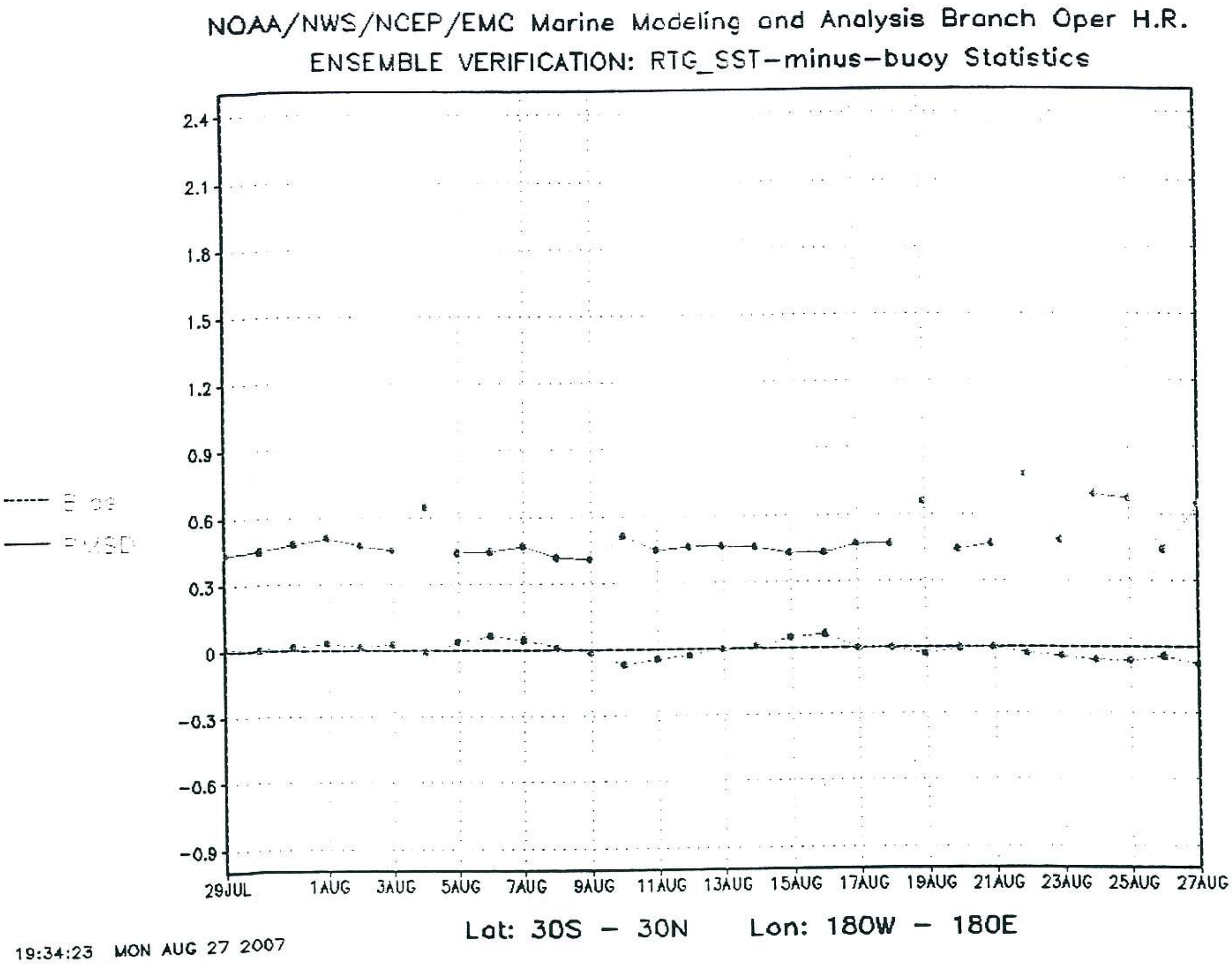
ENSEMBLE VERIFICATION: RTG_SST−minus−buoy Statistics



Lat: 30N − 45N Lon: 80W − 40W

19:34:42 TUE AUG 28 2007


NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch
ENSEMBLE VERIFICATION: RTG_SST-minus-buoy Statistics
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
Bias
RMSD
29JUL
1AUG
3AUG
5AUG
7AUG
9AUG
11AUG
13AUG
15AUG
17AUG
19AUG
21AUG
23AUG
25AUG
27AUG
Lat: 30S - 30N Lon: 180W - 180E
18:49:21 MON AUG 27 2007


NOAA/NWS/NCEP/EMC Marine Modeling and Analysis Branch Oper H.R.
ENSEMBLE VERIFICATION: RTG_SST-minus-buoy Statistics
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
29JUL
1AUG
3AUG
5AUG
7AUG
9AUG
11AUG
13AUG
15AUG
17AUG
19AUG
21AUG
23AUG
25AUG
27AUG
Lat: 30S - 30N Lon: 180W - 180E
19:34:23 MON AUG 27 2007

END of PAPER

OCTOBER 1,2007

RTG_SST_HR DP 0707 . doc